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Researches on Fuzzy Creep Compensation of Load Cell*

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Abstract: Creep is a critical specification of load cell. Based on the analysis of creep, a new compensation technique, fuzzy creep compensation, is presented in this paper. It firstly introduces the fuzzy recognition to determine loading situations. Compared to the other compensation methods, fuzzy creep compensation can avoid the complicated modeling of creep performance, and it is also proved to be an efficient and simple approach to improve the accuracy of load cell by experiments.

Key words: load cell, creep, fuzzy compensation

Creep is the change in load cell output occurring with time while under constant load and all environmental condition and other variables also remaining constant. As one of the key specifications of load cell, it is also the part mostly difficult to control. Generally, the creep of a load cell is composed of positive creep created by elastomer, and negative creep created by strain gage, adhesive and etc[1]. Traditional techniques to decrease the error created by creep include selecting different types of strain gages, relocating strain gages, etc[2]. To the applications where high accuracy requirement is employed, these techniques are unrealistic for their complexity and randomicity. In recent years, digital compensation is introduced to the manufacturing of new types of transducer to modify the error created by creep. Here, according to the creep model gotten from the tests under normal temperature, the micro-controller of a transducer calculates the creep error for compensating the output of the load cell. But, there are still some defects in this kind of compensation. Firstly, to most transducers whose creep performances are affected greatly by temperature, the model at normal temperature should not be used at high or low temperature, which means different models should be employed at different temperatures. But in factual applications, it is unrealistic. Secondly, as the creep model is an exponent function, a great deal of time of the micro-controller would have to be spent on the complex calculation of creep error, which would lower the dynamic response of the transducer. Thirdly, with the compensation said above, each transducer has to undergo a creep test for at least half an hour, to the large capacity of load cell. It will lead to a tremendous increase of test cost.

Based on the analysis given above, a new compensation technique of creep, fuzzy compensation, is presented in this paper. It is proved to be an efficient and simple approach to improve the accuracy of a transducer by experiments.

1 Creep Performance of Load Cell

Creep performance of a load cell is shown in Fig.1, which is composed of two different curves, loading curve L and unloading curve C. From the sketch map, it can be seen that the loading curve L can be divided into two sections, loading segment L_0 and creep segment L_1. In the loading segment L_0, the output of the load cell increases quickly to reach the actual weight W_0. Generally, the time spent on this section is so short that the creep occurs in this period can be ignored. Entering creep segment L_1, the output of the cell increases far more slowly than it does in section L_0. Normally, it can be regarded that the output change of the load cell in this section is only created by creep. The unloading curve C also consists of two items: unloading segment C_0 and creep-return segment C_1. During the unloading segment C_0, the output of the load cell decreases at a tremendous speed to point N, the creep value ε remains constant, i.e. the output change of load cell is mainly caused by unloading, and the creep error in this segment can be ignored. After that, the load cell enters creep-return

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segment C_1 and the output of the load cell returns to zero slowly.

Fig.1 is the demonstration of the creep performance of a load cell. But it usually does not exist in the factual application, the loading procedure often includes many repeats of loading or/and unloading cycle just as the situations shown in Fig.2, Fig.3 and Fig.4.

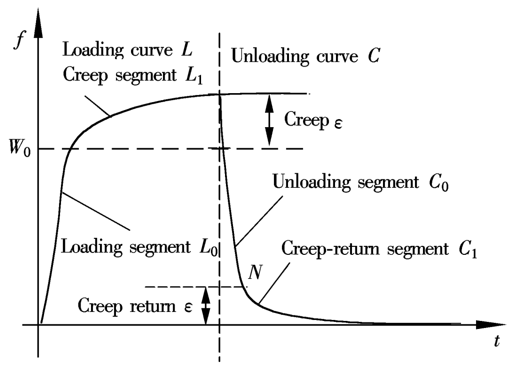

Fig.1 Creep performance of a load cell

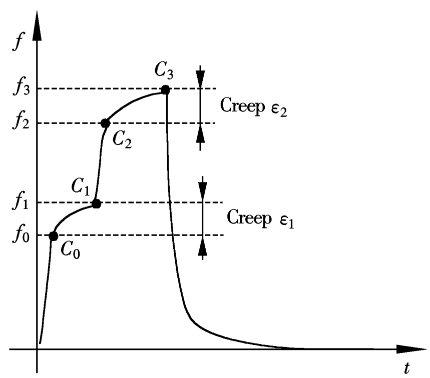

Fig.2 Creep performance under repeat loading

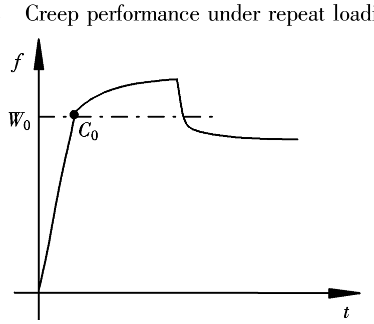

Fig.3 Creep under a loading/unloading cycle

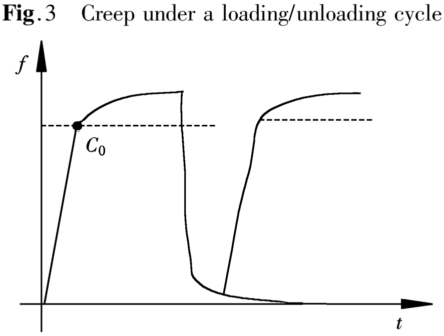

Fig.4 Creep under a loading/incomplete-unloading cycle

2 Compensation Principle

By observing the four creep curves given above, it can be easily seen that each loading or unloading procedure can be divided into two sections, sharp change segment of the output and slow change segment of the output. Actually, the sharp change segment is the loading/unloading segment in which the output change is actual weight change and the new creep error can be ignored. Meanwhile, the slow change segment is the creep/creep-return segment in which the output change is the new creep error and the actual weight remains the same.

Based on the analyses above, Fig.2 is taken as an example to introduce the principle of creep compensation.

2.1 Working procedure analysis of load cell

Now, take a free point on the curve in Fig.2 as a research object to analyze the creep performance presented in the diagram. When point C is on the left side of point C_0, the transducer works on the loading segment whose original weight and creep are all zero, and W_C, the actual weight at point C, is equal to the output of the load cell f_C. Then, with the time elapsing, point C approaches point C_0 little by little. When point C reaches the end point of the loading segment C_0, the output of the load cell f_0, is equal to W_0 — the actual weight loaded on the transducer. Exceeding point C_0, the transducer works on the creep segment while the actual weight keeps constant. In this section, due to the creep error of load cell ε, the output of the load cell will increase continuously at a much lower speed. With the time elapsing, point C reaches point C_1, and the creep error ε reaches its final value ε_1. Once point C exceeds point C_1, the load cell again works on the loading segment whose original weight is W_0 and original creep is ε_1. In this section, the creep of the load cell remains ε_1 and the actual weight can be calculated by the following formula:

$$W_C = W_0 + \Delta W = W_0 + \Delta f = W_0 + (f_C - f_1) = f_C - (f_1 - W_0) = f_C - \varepsilon_1 \qquad (1)$$

where W_C is the actual weight at point C; ΔW is the weight change from point C_1 to point C; Δf is the output change from point C_1 to point C; f_1 is the output at point C_1 which includes the original weight W_0 and original creep ε_1; f_C is the output at point C.

The loading segment is ended at point C_2. After that, the load cell works on the creep segment where the actual weight is kept as a constant, so the creep in this section can be calculated by the following formula:

$$\varepsilon_C = \varepsilon_1 + \Delta f = \varepsilon_1 + (f_C - f_2) \tag{2}$$

where ε_C is the creep at point C; Δf is the output change from point C_2 to point C; f_2 is the output at point C_2; f_C is the output at point C.

Analyzing the creep performance in Fig.3 and Fig.4, similar conclusion can be gotten. That is, to each segment of the curves in Fig.3 and Fig.4, formulas of the creep and weight are the same as that of Fig.2. The only difference is the sign of ΔW and Δf.

2.2 Creep compensation principles

Analyzing formula (1) and formula (2), it can be concluded that to a point on the loading/unloading curve whose original weight and original creep are all zero, if the point is located on the loading or unloading segment, the actual weight at the point, W_C, can be calculated by the following formula:

$$W_C = W_0 + \Delta W = \Delta W = \Delta f = f_C$$

If the point is located on the creep or creep-return segment, the actual creep at the point ε_C can be calculated by the following formula:

$$\varepsilon_C = \varepsilon_0 + \Delta f = \Delta f = f_C - W_C$$

where f_C is the output at point C; ΔW is the weight change of the loading/unloading curve.

It is obvious that the result gotten here is the same as that gotten in chapter 2.1. From all these analyses, we can draw a conclusion that formula (1) and formula (2) can be used in the calculation of the creep and weight at point C_0, which proves the generality of formula (1) and formula (2).

Extending formula (1) and formula (2) to all the working cycles of a load cell, we can get the approach to calculate the creep and the weight of a load cell as follows.

To a free point on the loading/unloading curve of the load cell whose original weight is W_0 and creep is ε_0.

1) If the free point is located on the loading or unloading segment, the functions of the weight W_C and creep ε_C are

$$\left.\begin{aligned} W_C &= f_C - \varepsilon_0 \\ \varepsilon_C &= \varepsilon_0 \end{aligned}\right\} \tag{3}$$

2) If the free point is located on the creep or creep-return segment, the functions of the weight W_C and creep ε_C are

$$\left.\begin{aligned} W_C &= W_0 \\ \varepsilon_C &= f_C - W_0 \end{aligned}\right\} \tag{4}$$

where f_C is the output at free point C.

According to the different situations of using formula (3) and formula (4), it is necessary to judge whether the load cell works in creep/creep-return segment or in loading/unloading segment first. Analyzing the loading situation on C_0 — the end point of loading segment in Fig.2, Fig.3 and Fig.4, it can be easily found that the change ratio of load cell output has been greatly changed on point C_0. So the point C_0 will be the start point of creep segment, therefore, by using the formula (3) or formula (4), the actual weight W_C can be easily worked out.

3 Fuzzy Creep Compensation

Using the compensation principle introduced above, we can calculate the creep and weight of a load cell at any time of its working cycle. Here, a concept of "sharp output change" is involved, with which we can describe the creep/creep-return segment as a segment of "slow output change", and the loading/unloading segment as a segment of "sharp output change". In factual applications, it is hard to define the concept of "sharp change"; therefore, the fuzzy recognition is introduced here for the loading conditions judgement.

3.1 Principle of fuzzy recognition

To different kinds of objects, there are different recognition principles. According to the character of the output change, the following principle is employed in its recognition[3-5].

Assuming

$$A_i \in F(U) \quad i = 1,2,\cdots,n$$

$$u_0 \in U$$

If there exists an integer, i, which fulfills the following condition:

$$A_i(u_0) = \max\{A_1(u_0), A_2(u_0), \cdots, A_n(u_0)\}$$

Then, it is taken for granted that u_0 belongs to set A_i relatively.

3.2 Recognition of output change

Here, assume that f_0 is the last output, f_t is the current output. Then the current output change of the load cell, Δf, is

$$\Delta f = f_t - f_0$$

The relative output change is

$$\eta = \Delta f / f_t$$

The rate of relative output change is

$$\nu = \eta/\Delta T$$

where ΔT is the sampling time which is kept as a constant during the whole application. Therefore relative output change η can be employed to represent the rate of relative output change ν to simplify the data process of the load cell.

Take the relative change of the output during a sampling time as the research object, A_1 is the fuzzy set ⟨sharp change⟩, and A_2 is the fuzzy set ⟨slow change⟩, the membership functions of two sets are

$$A_1(\eta) = \begin{cases} 0 & \eta \leqslant \frac{1}{10\,000} \\ \left(\frac{\eta - \frac{1}{10\,000}}{\frac{9}{10\,000}}\right)^2 & \frac{1}{10\,000} < \eta \leqslant \frac{1}{1\,000} \\ 1 & \eta > \frac{1}{1\,000} \end{cases}$$

$$A_2(\eta) = \begin{cases} 1 & \eta \leqslant \frac{1}{10\,000} \\ 1 - \left(\frac{\eta - \frac{1}{10\,000}}{\frac{9}{10\,000}}\right)^2 & \frac{1}{10\,000} < \eta \leqslant \frac{1}{1\,000} \\ 0 & \eta > \frac{1}{1\,000} \end{cases}$$

In actual applications, we firstly use the functions given above to calculate the two membership function values to judge whether the load cell works on the creep/creep-return segment or on the loading/unloading segment. Then, the actual weight and creep will be worked out by using formula (3) or formula (4).

3.3 Realization of fuzzy compensation of creep

Here, the creep performance in Fig.2 is taken as an example to reveal how the fuzzy creep compensation works. The illustration shows that on the left side of point C_0, the load cell begins to work from the original point at which initial value of the creep and weight are both zero. Passing the first loading segment in which the output is changed sharply, the load cell enters the first creep segment in which the output increases slowly. During this period, the micro-controller of the load cell reads the output, calculates and compares the two membership function values, $A_1(\eta)$ and $A_2(\eta)$, then memorizes and sends out the current output as the actual weight. At the first point where $A_1(\eta)$ is less than $A_2(\eta)$, this point is taken as the start point of the creep segment. From this moment on, the micro-controller sends out the output at the start point of creep segment as actual weight and keeps updating the output change from this point as creep error in the memory until $A_1(\eta)$ is greater than $A_2(\eta)$. Once it occurs, the load cell is again working in loading segment, the micro-controller subtracts the creep error ε which is stored in the memory at the end point of creep segment from load cell current output f and sends out as the actual weight W until the next creep segment occurs. Once it happens i.e. $A_1(\eta)$ is less than $A_2(\eta)$ again, the microcontroller will repeat the process in creep segment.

The above describes working process of the micro-controller in the application. Since it is just the example of positive creep compensation, a declaration should be mentioned is that the compensation above is also suitable for negative creep.

4 Experiments

To verify the compensation method described above, a typical experiment has been done as follows and results gotten in the experiments are shown in Tab.1.

The following are the steps employed in the verification(the whole test is under 40 ℃).① Load 10 kg on a 30 kg load cell; ② 2 min later, load another 10 kg to the load cell; ③ 2 min after ②, unload all the loads on the load cell; ④ 2 min after ③, load 30 kg to the load cell, then wait for 5 min. In each step of the experiments, the output of the load cell should be gotten at the beginning and the end of each loading.

$$f(t) = a \times w_c \times [1 + e^{\frac{-t}{\Delta T}}] \quad (5)$$

where W_C is the current weight; a is the compensation

Tab.1 Experiment results

Actual weight/kg	Time/s	Uncompensated		Compensated by new method		Compensated by formula (5)	
		Output/kg	Error · $(F.S)^{-1}$/%	Output/kg	Error · $(F.S)^{-1}$/%	Output/kg	Error · $(F.S)^{-1}$/%
10	0	10.000 3	0.001	10.000 3	0.001	10.000 3	0.001
10	120	10.003 9	0.013	10.000 3	0.001	10.001 8	0.006
20	0	20.004 2	0.014	20.000 9	0.003	20.0018	0.006
20	120	20.006 3	0.021	20.000 9	0.003	20.003 0	0.010
0	0	0.006 0	0.020	0.000 6	0.002	0.003 3	0.011
0	120	0.001 5	0.005	0.000 6	0.002	0.001 2	0.004
30	0	30.001 8	0.006	30.001 5	0.005	30.001 2	0.004
30	300	30.015 3	0.051	30.001 2	0.004	30.008 7	0.029

Note: F.S means full scale.

parameter gotten under normal temperature; ΔT is the sampling period and t is the time variable.

Formula (5) is to calculate the creep error which we have mentioned in the first paragraph of this paper.

From the test results in Tab.1, we can easily draw a conclusion that the new method for creep compensation is efficient and is better than that compensated by formula (5).

5 Conclusion

This paper provides a detailed introduction of fuzzy compensation of the creep. It firstly recommends the fuzzy recognition to determine the loading situations i.e. the rate of output change with which the start point of a creep segment of a loading/unloading curve is determined and the actual weight can be calculated. Compared to other compensation techniques, it is a new, simple, reliable and accurate compensation method which not only avoids the complicated modeling of creep performance but also prevents from environmental influence.

References

[1] Ma Liangcheng. *Electronic measurement & sensor technology* [M]. Beijing: China Metrological Press, 1993.396 - 408. (in Chinese)

[2] Tao Baoqi. *Strain gage based transducer* [M]. Beijing: National Defense Industrial Press, 1993.9 - 64.(in Chinese)

[3] Li Jingru, Sun Qian, Liu Chongqing. Pattern recognition based on fuzzy set theory[A]. In: *Asian Proceedings Control Conference*[C]. 1994.709 - 711.

[4] Mamdni E H. Application of fuzzy algorithms for control of simple dynamic plant[J]. *Proc IEEE*, 1974, **121**(12): 1585 - 1588.

称重传感器蠕变的模糊补偿方法研究

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摘　要　本文介绍了对传感器蠕变进行补偿的新方法,首次引入模糊识别的方法来确定载荷的变化情况,该方法可实现蠕变实时精确补偿,简便易行,避免了繁琐的传感器蠕变模型的建立和实现过程.实验证明这种方法精度很好.

关键词　称重传感器,蠕变,模糊补偿

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